# SUPERFLUID HELIUM ORBITAL RESUPPLY COUPLING*

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## ABSTRACT

The resupply of superfluid helium to satellites and other space-based experiment packages can increase the useful longevity of these devices far beyond their present life expectancies which are many times determined by the supply of helium coolant. The transfer of superfluid helium to spacecraft in space will require a reusable coupling that functions at 1.8° Kelvin with little heat leak and low pressure drop. Moog has designed the Helium II Resupply Coupling to meet these operational requirements. Initially, the coupling manual mode operation will be demonstrated on orbit by an EVA crew member during the Space Shuttle borne SHOOT (Superfluid Helium On-Orbit Transfer) experiment. The ultimate application will use robotic (automatic) coupling operation to which the present design readily adapts.

This paper describes the utilization of Moog's exclusive RSO (Rotary Shut-Off)[1] technology in the development of the Superfluid Helium Resupply Coupling. The coupling not only performs the function of a flow control valve and disconnect but also provides adequate safety features for a shuttle launched man-rated payload. In addition, the coupling incorporates the necessary features to provide the high thermal isolation of the internal flow path from the external environment.

## INTRODUCTION

The resupply of Superfluid Helium is essential to the longevity of many satellites and experiment packages. The transfer of Superfluid Helium requires a reusable coupling that operates at 1.8° K with low heat leakage from the external environment into the liquid helium and with minimal pressure drop. Moog Inc. has designed the Helium II Resupply Coupling to meet these operational requirements for a minimum of 20 resupply missions. The coupling will be operated by an Extra Vehicular Activity (EVA) crew member; therefore, it meets Payload Bay and EVA safety and reliability requirements. The He II Resupply Coupling will fly on the Superfluid Helium On-Orbit Transfer (SHOOT) Flight Demonstration which will demonstrate the advanced technology required for Superfluid Helium transfers. SHOOT, scheduled to fly on the Shuttle in 1991, will include an EVA demonstration of the coupling engagement and disengagement plus the transfer of Superfluid Helium. Figure 1 depicts the engaged coupling installed in the SHOOT experiment assembly with the transfer line connected to the tanker half of the coupling and the spacecraft half mounted on the helium Dewar.

Low heat leakage is required to assure that liquid helium flow can be established starting with a relatively warm coupling. If heat input to the fluid flow path is too large, the rapid boil-off and attendant pressure rise will prevent the establishment of liquid helium flow given the relatively low pumping pressures available in the helium transfer system. The low pumping pressure head available from the selected SHOOT thermal-mechanical pump, which consists of a porous plug and an electrically applied thermal gradient, also dictates that the coupler provide a minimal impedance flow path. This pumping scheme provides a pump head of the order of a few psi.

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1 One or more of the following U.S. Patents Apply: 4,473,211; 4,627,598; 4,664,149.
*This work was performed under Contract NAS9-17872 with NASA/Johnson Space Center.
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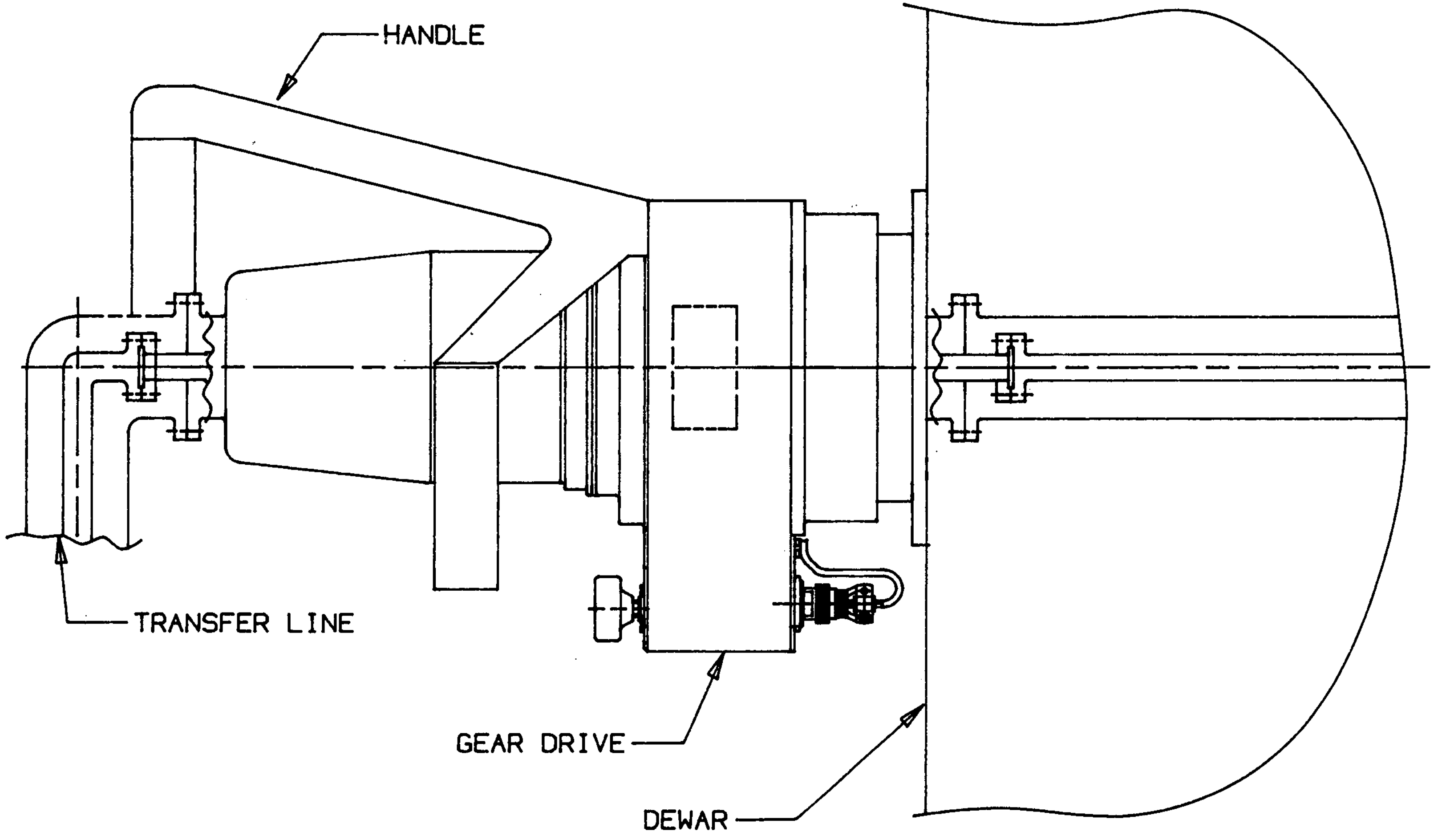


FIGURE 1 SUPERFLUID HELIUM RESUPPLY COUPLING INSTALLED IN SHOOT EXPERIMENT ASSEMBLY

Moog Inc. began development of the HE II Coupling in August, 1987 utilizing Moog's patented Rotary Shut-Off (RSO) disconnect technology. It was recognized that the RSO technology, with modifications, offered attributes which could be successfully exploited for the Helium II Resupply Coupling.

## RATIONALE FOR DESIGN APPROACH

The RSO design has several advantages over both poppet and traditional ball type valves. Poppet devices usually consist of a conical poppet mounted on a valve stem which guides the poppet through its stroke. The poppet, positioned in the flow path, presents an impediment to flow with an attendant increase in pressure drop. Conventional ball valves typically have a flow passage machined through a sphere which is rotated by a drive shaft against a seal. The traditional ball valve design minimizes pressure drop by providing an unobstructed flow path, but the design does require a large preload to affect a leak tight seal. The large preload is required because these types of valves typically restrict the ball to rotation about a fixed drive shaft axis and do not permit the sphere to self-center on the seat. At cryogenic temperatures, seat materials will exhibit little compliance and therefore higher preloads are required to achieve acceptable leakage rates. The poppet and seat must mesh perfectly to ensure adequate sealing at cryogenic temperatures. The poppet preload required for this application is calculated to exceed 400 lbf.

The RSO flow control devices incorporated in the He II Resupply coupling avoids these deficiencies. A ball valve element is driven by an eccentric pin mounted on a mandrel. This drive pin loosely engages slots machined into the ball. The linkage between the mandrel and the ball efficiently transmits the forces required to open and close the ball while affording it considerable compliance to permit self-centering. The ball is allowed to adapt (self center) to changes in seat conditions such as thermal distortion, wear or cold flow. Seat preload is evenly and concentrically distributed around the ball seal interface. These factors combine to reduce preload force required for sealing. Since all the candidate seal materials are hard at cryogenic temperatures, they are likely to scratch the sealing surface if the ball is rotated under any appreciable preload. The He II Resupply Coupling design embodies a mechanism that automatically relieves the preload before the ball rotates open.

Another important consideration in developing the design concept was to provide for automatic mechanical sequencing of the coupling , eliminating any requirement for the EVA operator to remember and perform a series of operations in a particular order. In the process of engaging and disengaging the He II Resupply Coupling, flow control valve actuation and the make and break of fluid containment and vent cavity seals is accomplished automatically. The automatic sequencing characteristic results in a safety and an operational benefit for the coupling. From the safety standpoint, the automatic sequencing eliminates the possibility of opening the flow control valve prior to coupling engagement and establishment of the proper interface seals or, conversely, disengaging the coupling prior to closure of the flow control valve. Operationally, automatic sequencing provides for direct adaptation to robotic operation without any modification to the coupling or complex demands on the robot.

## FLOW CONTROL VALVE MECHANICAL OPERATION

The basic mechanical operation of the primary component of the coupling, the ball valve element, is portrayed in the schematic diagrams shown in Figure 2. Figure 2a shows the flow control valve in the closed position with the ball preloaded against the seal. The preload is provided by Belleville springs which squeeze the ball between the seat and the thrust bearing as indicated in the diagram.

A drive pin in the mandrel, eccentrically located with respect to the center of the ball, rotates the ball into the open and closed positions when the mandrel is moved with respect to the ball. The valve cartridge, containing the ball, seat, Belleville springs, and thrust washer, is permitted to move with respect to the mandrel via the helical return springs.

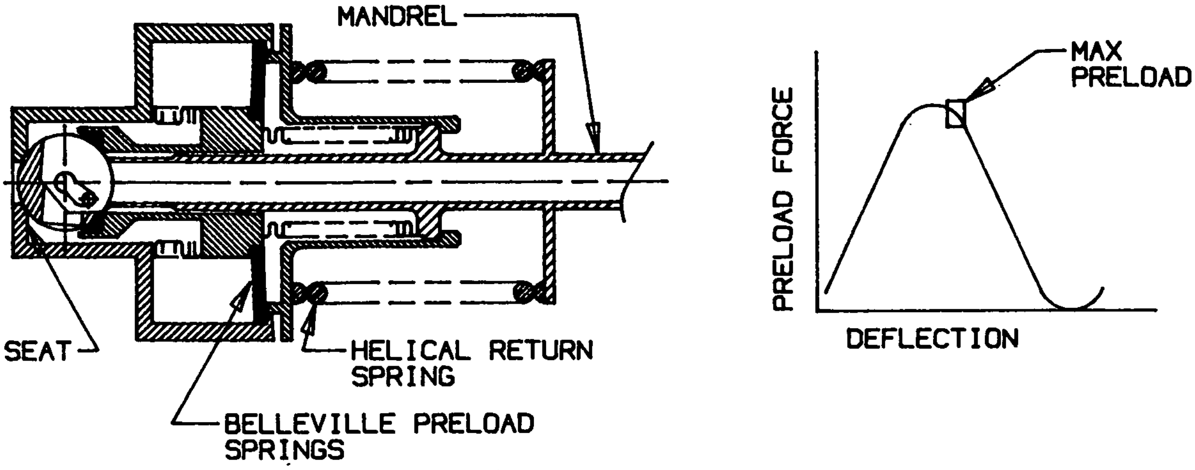


FIGURE 2a MAXIMUM PRELOAD

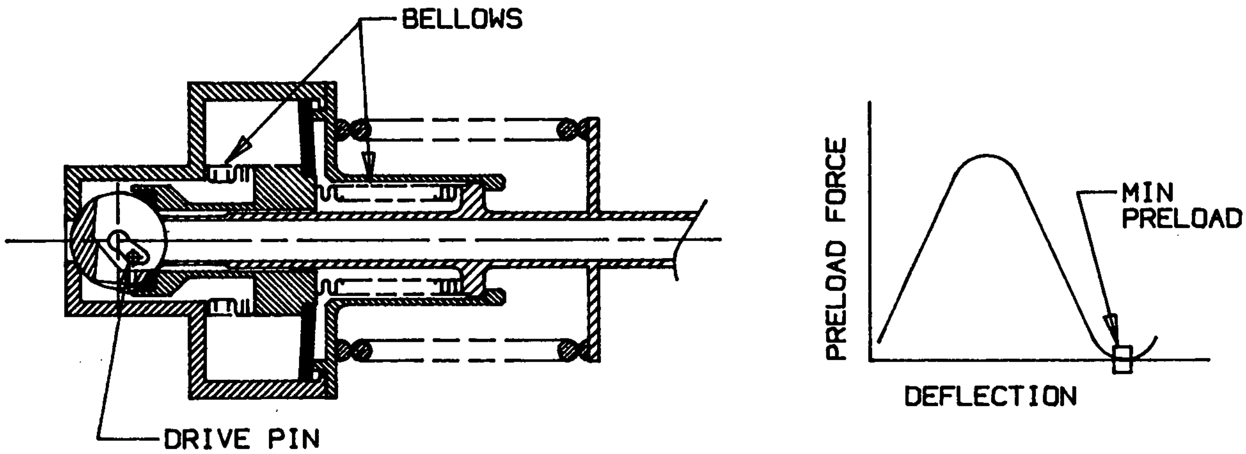


FIGURE 2b MINIMUM PRELOAD

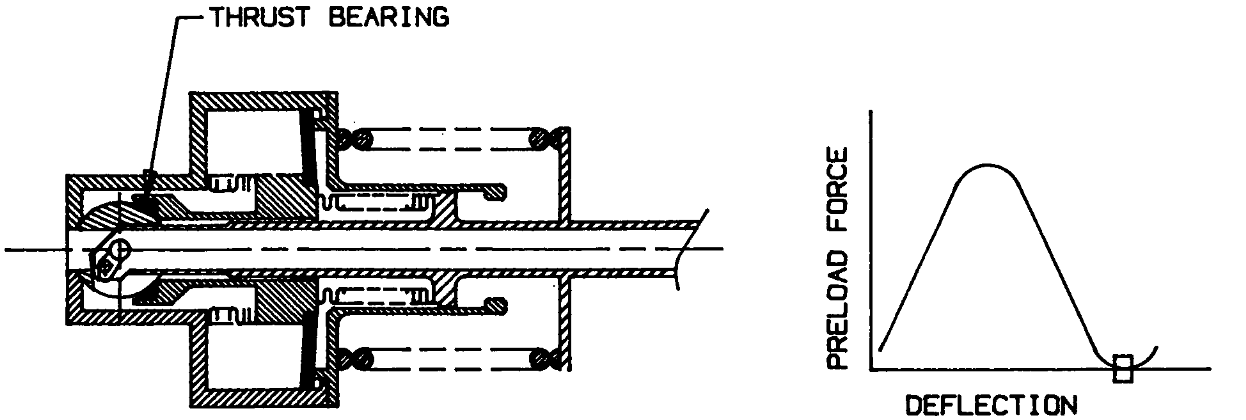


FIGURE 2c BALL ROTATED OPEN

FIGURE 2 FLOW CONTROL BALL PRELOAD UNLOADING MECHANISM

The Belleville preload springs are designed to exhibit a negative spring rate when stroked from their initial preload position as indicated by the force deflection curves in Figure 2. Preload is removed from the ball prior to commencing ball rotation by stroking the Belleville springs from maximum load to essentially zero load. This initial stroking of the Belleville springs is accomplished by setting the helical spring initial preload load slightly above the Belleville preload such that during the beginning of stroking of the valve cartridge with respect to the mandrel, the Bellevilles deflect instead of the helical springs. Ball rotation is delayed until preload removal is achieved by providing an elongated slot in the ball for the drive pin to traverse prior to applying a torque to the ball. Comparing Figures 2a and 2b shows the relative relationships of the various parts of the flow control mechanism for the preloaded and unloaded situations, respectively. Note in Figure 2b that after preload removal is completed, the drive pin in the mandrel is now located in the ball slot such that further motion of the mandrel with respect to the ball will result in a torque being applied to the ball. Figure 2c shows the flow control valve in the fully open position following full stroking of the valve cartridge with respect to the mandrel. Figure 2 also shows the two bellows assemblies required to provide fluid seals between the moving parts of the flow control assembly.

## COMPONENT DESCRIPTIONS

### Flow Control Ball and Seat

The primary component of the Superfluid Helium Resupply Coupling is the flow control ball, whose basic operation has just been described. The ball is made from a standard one inch diameter ball bearing which is machined to provide the desired straight through flow passage and the drive pin slot geometry. The ball is made from 300 series stainless steel and provides a flow seal against a high purity fully annealed copper seat. The 300 series stainless steel is an excellent cryogenic material in that it does not exhibit a brittle transition common to the precipitation hardened stainless steels. The fully annealed copper was selected for the seat material because it is essentially the softest material available at liquid helium temperature, softer in fact than plastics. Clearance between the drive pin in the mandrel and the slot in the ball allows the ball to be self-centering when affecting a closure against the copper seat.

### Thermal Leakage

Thermal isolation of the flow passage and flow control ball from the warm exterior of the coupling is accomplished by using low thermal conductivity fiberglass composite tubes to form the structural connection between the outer and inner portions of the coupling. Additional thermal insulation of the inner cold structure is achieved by a guard vacuum space and Multiple Layer Insulation (MLI). The guard vacuum prevents convective heat transfer into the cold interior while the MLI reduces radiative heat transfer. The design is intended to limit heat leak to less than 1.0 Watt. A low heat leak is required to permit the establishment of liquid helium flow in a warm coupling. Initial superfluid helium flow will boil and form a momentary back pressure tending to restrict further helium flow. With sufficiently low heat leak the pressure rise of succeeding boil off cycles of helium pulses will slowly decrease until steady state liquid helium flow is achieved. If the coupling heat leak is too large, steady state liquid helium flow will not be established.

The fiberglass epoxy thermal isolator tubes are attached to the metallic portions of the coupling by epoxy adhesive which forms both the structural bond and the hermetic seal required to maintain the guard vacuum. Component tests of isolator tubes and the bonded joints have demonstrated the ability of the assembly to withstand the pressure and thermal loadings required by the coupling operating environment. On-going tests are in process to investigate gaseous helium permeability of the isolator tubes and to determine methods to

limit such permeability to acceptable limits. Parameters examined in these development tests include tube materials, fabrication processes, and sealant coatings. The importance of low helium permeability of the isolator tubes results from the fact that any permeability of the tube degrades the guard vacuum which in turn will result in a greater coupling heat leak. Permeability is only a concern in the ground environment during the launch phase from the time the fluid transfer system is secured until launch occurs.

MLI is employed on the surfaces of the inner cold structure to minimize the magnitude of the radiation component of the total coupling heat leak. This highly reflective layered material is positioned such that wherever there is a line-of-sight relationship between the outer warm structure and the inner cold structure, the MLI is interposed. Because it is not feasible to install MLI between the closely spaced inner and outer isolator tubes, the two tubes have been axially located with respect to one another such that adjacent locations along the respective tubes are essentially at the same temperatures. This matching of temperatures on the adjacent tubes minimizes radiative heat transfer between the two.

<u>Fluid Seals</u>

The coupling includes four groups of functional dynamic seals. These seals are bellows, spherical ball and seat, spring loaded Teflon-jacketed face seal, and spring loaded Teflon-jacketed radial seals. Indium is employed for two static seals within the assembly and welds are used to seal the remaining portions of the metallic structure. In addition, adhesive is used as a sealant between the composite thermal isolator tubes and the adjacent metal structure. The discussion that follows here will address the dynamic seals excepting the flow control ball and seat which were described earlier.

The two bellows assemblies used in each coupling half form the flexible fluid barrier between the various parts which must move with respect to each other in the flow control assembly. The shorter of the two bellows provides for the relative motion between the structure containing the flow control seat and the thrust bearing located on the upstream side of the ball. These structures move relative to one another when preload is applied and removed from the flow control ball. Similarly, the long bellows provides a flexible seal which allows the mandrel to move with respect to the flow control ball during ball rotation to open and close the flow passage. These hydroformed bellows assemblies are made of Inconel 718.

The cold seals prevent the Helium from leaking into the vent cavity when the two coupling halves are fully engaged and the balls are open. Two concentric spring loaded Teflon-jacketed face seals on the tanker half coupling mate with corresponding polished metallic surfaces on the spacecraft half coupling when the coupling is mated. In addition, a metal-to-metal seal is effected as the third and innermost concentric seal when the coupling halves are mated. This metal-to-metal seal serves as a safety against a catastrophic failure of the two face seals.

Whereas the cold seals define the cold end of the vent cavity, the warm seals are the warm end counterpart. These seals are contained on the outer structure of the tanker half coupling and mate with the spacecraft half coupling when engagement of the two coupling halves commences. These radial seals are also of spring-loaded Teflon-jacketed construction. Two seals in series are employed to provide redundancy.

<u>Vent Cavity</u>

The vent cavity is that volume between the two engaged coupling halves defined by the cold seals, warm seals, and the respective coupling half surfaces. A vent port is available on each coupling half to provide access to the vent cavity as required for testing or operational

purposes. On the ground, this cavity will be either evacuated or filled with gaseous helium. The purpose of filling the vent cavity with helium is to prevent the entry of air and moisture past the warm seals with the attendant problem of liquefaction upon launch into the cold environment of space. Liquid water or air are contaminants which can impair the operation of the entire helium transfer system.

### Gear Drive

Engagement of the two coupling halves from the soft dock position is accomplished by applying a torque to the gear drive input shaft either manually or through the use of a power tool. The gear drive consists of a single reduction worm and ring gear with a 7.75:1 ratio. The ring gear, to which is bolted to a cylindrical sleeve containing a male thread, rotates on ball bearings on the outer periphery of the tanker coupling half. This thread, when mated to the stationary thread on the spacecraft half of the coupling, provides the actual engagement and disengagement motion. Approximately 15 turns of the worm gear drive input shaft will fully engage the two coupling halves. Input torque is designed to be less than 50 in.-lbf.

To prevent backdriving of the worm gear at full coupling engagement, a lock-up mechanism is provided at the end of the worm gear opposite the input shaft. The lock-up mechanism consists of three spur gears; an idler gear, a locking gear on a manually operated sliding shaft, and a gear on the end of the worm gear shaft. If all three spur gears are mutually engaged, motion of the worm gear is prevented. By sliding the locking gear axially out of engagement, motion of the worm gear can occur.

A mechanical position switch inside the gear drive housing provides an electrical signal indicating full coupling engagement. In addition, a visual indicator system is provided on the outside of the spacecraft coupling half to further ascertain the engagement status of the coupling.

## OPERATIONAL SEQUENCE FOR MATED COUPLER

A brief description of the coupling engagement sequence is outlined in the following paragraphs. Figure 3 shows the two coupling halves completely separate prior to commencing the engagement sequence. Figure 4 shows the coupling in its fully engaged position.

### Alignment Prior to Engagement

The tanker half includes the handles used by the EVA crew member to maneuver the coupling half and transfer line. The handles and gear drive rotate +/- 20 degrees on bearings mounted on the tanker half outer body. This rotation allows the crew member to rotationally align the two coupling halves without transmitting torsional forces to the transfer line. The maximum possible rotational displacement required of the tanker drive mechanism with respect to the spacecraft half is +/- 5 degrees. This rotation is required to engage a 10 degree interval anti-torque spline between the two coupling halves.

### Soft Dock Operation

When the crew member has successfully rotationally aligned the two coupling halves, a low level axial force (<25 lbs) will soft dock the device. At soft dock, spring loaded ball bearings on the spacecraft half snap over the first engagement thread on the tanker half. Soft dock serves two purposes; both coupling halves are secured to each other freeing the crew member to operate the drive gear mechanism, and the ball bearing engagement in the threads ensures proper thread engagement during drive gear operation.

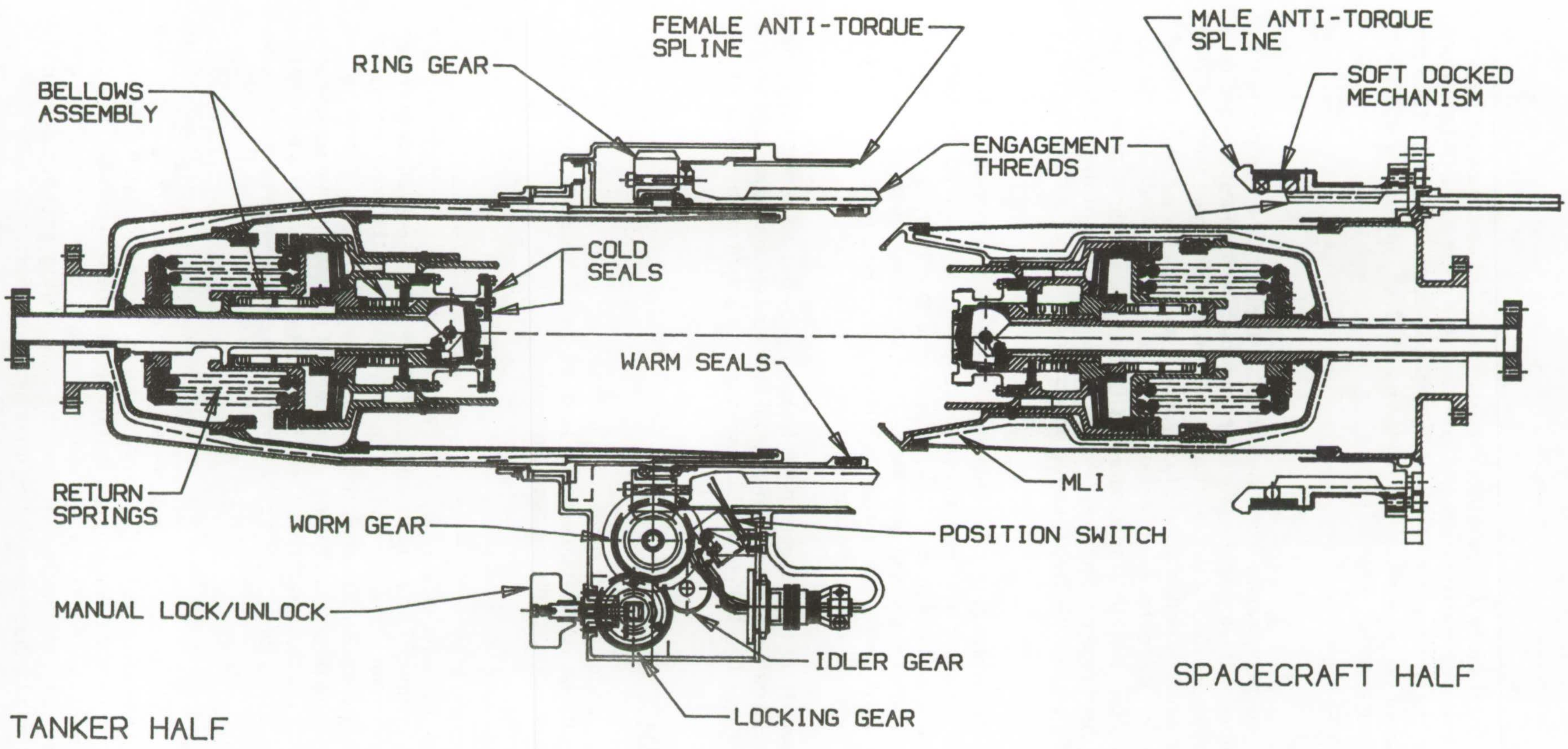


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FIGURE 3 SUPERFLUID HELIUM RESUPPLY COUPLING DISENGAGED

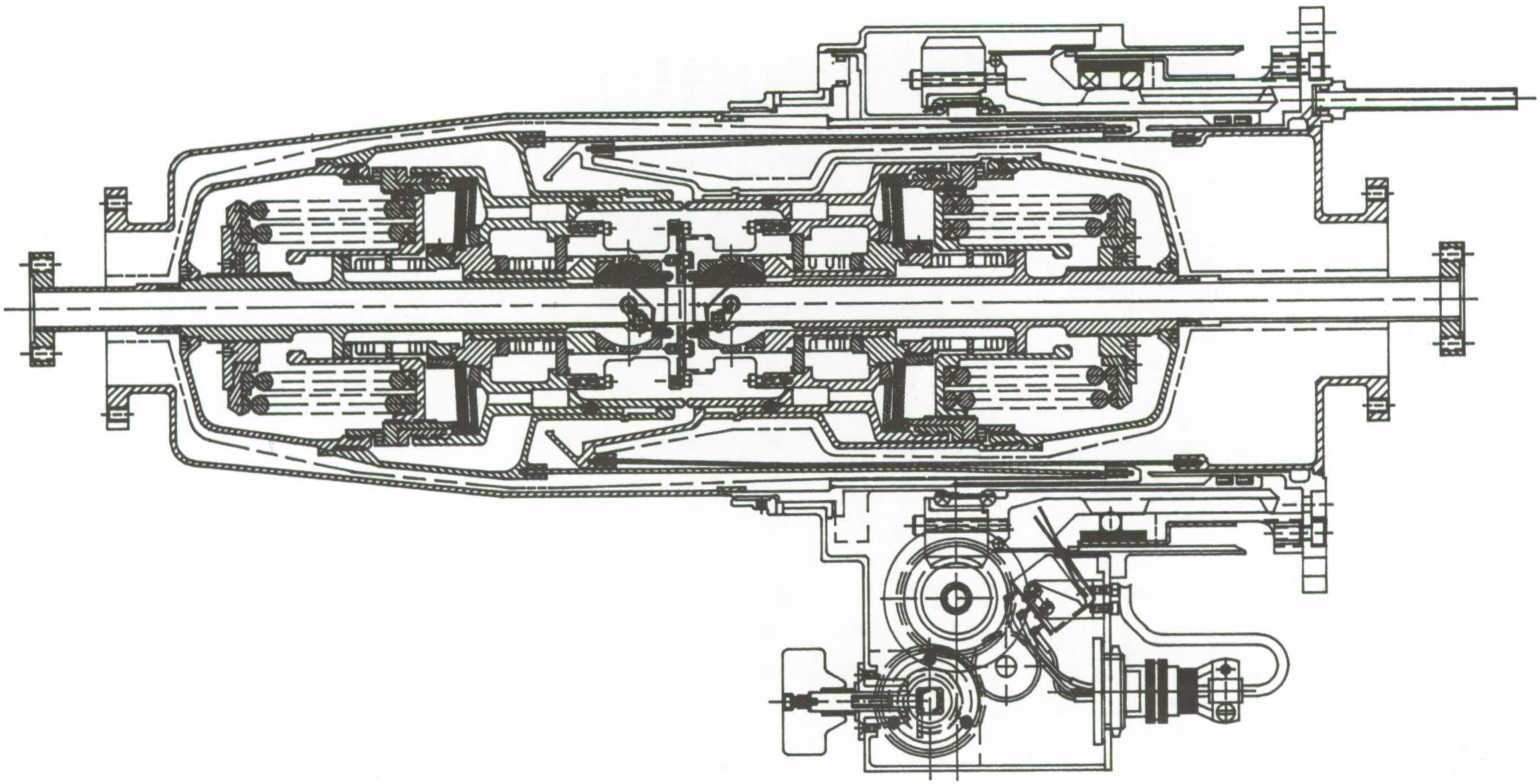

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FIGURE 4 SUPERFLUID HELIUM RESUPPLY COUPLING FULLY ENGAGED

Warms Seals Engaged

After the coupling is soft docked, further engagement is achieved by driving the gear drive input shaft using a hand rachet or EVA power tool. The drive shaft transmits torque to the worm gear which drives the ring gear and male threaded sleeve on the tanker half. The anti-torque spline between the two coupling halves reacts the gear drive torque internally so that no external forces are applied to the coupling halves or the transfer line. The coupling halves continue to move axially toward each other until the warm seals on the tanker half mate with the spacecraft half.

Concurrently with the mating of the warm seals, mechanical locking detente collars on the respective halves make contact. As further engagement of the coupling ensues, these locking collars are stroked. Before the locking collars come together, the ball bearing assembly attached to the collars prevents the release of the preload on the flow control ball and therefore, insures proper mechanical sequencing of flow control ball operation.

Cold Seals Engaged

When the flow control ball retainers come together, the cold seals are fully mated. At this point in the engagement sequence the two spring-loaded face seals and the metal-to-metal seal are fully loaded and leak tight. The locking detentes are fully stroked and the detente balls release the flow control ball mechanism to permit preload removal from the copper seat.

Preload Removed

Further engagement of the coupling of the order of 0 .10 inches removes the preload from the flow control ball, as discussed earlier, by deflecting the Belleville springs to their zero load position. A second set of Belleville springs shown in the cross-section drawings for the coupling are required to return the primary Bellevilles to their loaded position when the couplings are disengaged and preload must be re-applied to the flow control ball. Upon completion of preload removal, the Belleville preload springs are mechanically shunted to avoid overstroking and the mandrel drive pin has traversed the slot clearance in the ball such that further engagement will rotate the ball.

Flow Control Ball Rotation

Following preload removal, progressive engagement of the couplings rotates the flow control ball 90° to its full open position. At full open the flow passage is a unobstructed hole, offering no more resistance to flow than a straight through pipe. Mechanical adjustments, internal to the coupling halves, facilitate adjusting the full engagement stroke to insure that the flow control ball is always properly aligned to achieve an unobstructed flow passage at full coupling engagement.

Hardware Status

All component parts for the development units are fabricated and initial assembly and test is underway. Two development units will be built and tested. Testing will be conducted at ambient, liquid nitrogen,liquid helium, and superfluid helium temperatures.

## SUMMARY

A NASA/JSC sponsored development program is underway at Moog Inc. to design, build and test a Superfluid Helium Resupply Coupling capable of EVA operation in the Space Transportation System cargo bay. The SHOOT Program will test the flight design on a future STS mission during which the coupling will be used to transfer superfluid helium between two helium Dewars. The coupling hardware is designed with the necessary dual redundancy in critical seal areas to satisfy orbiter safety concerns.

The hardware employs a patented rotating ball flow control design featuring a unique mechanism for removing primary flow control seat preload prior to ball rotation. In addition, the hardware has been designed to survive and function in the cryogenic environment of superfluid helium through judicious selection of materials suitable for the temperature extremes of 1.8 degrees Kelvin to 350 degrees Kelvin. Composite materials are used in the design to aid in limiting thermal leakage to less than 1.0 Watt.

An important characteristic of the coupling design is the automatic mechanical sequencing which insures that all the required functions for making and breaking seals, flow control, thermal leakage control, and personnel protection is inherent in the design and requires no operator input. All the required functions occur in the proper sequence solely as a consequence of engaging the two coupling halves. Besides the obvious safety implications of the automatic sequencing, this attribute facilitates adapting the coupling to robotic or automated operation. Automation requires only that the drive system be removed from the coupling and that the coupling be installed on a carrier plate that would perform the engagement function currently performed by the drive in the present design.